

Solving the Climate/Energy Problem

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**"Scientists are
necessary,
but not
sufficient to
solve the
climate
problem"**

**Dr. Ralph Cicerone,
President of the National Academy of Science, November 2007**

Outline

1. Why we are so sure there's a problem

- Dancing molecules and "heat rays"
- About half the CO_2 stays in the air "forever"

2. What We Can Do About It

- Climate "Wedges" concept
- Feasible solutions with today's technology

3. How to Make it Happen

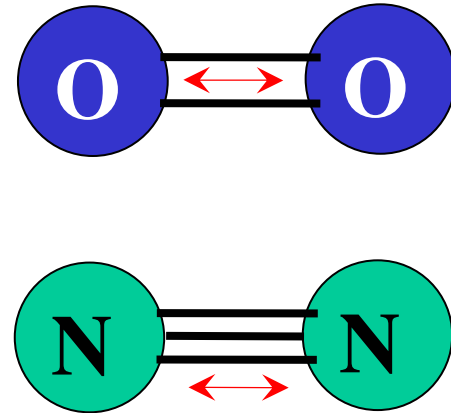
- Carbon "pricing"
- A new Industrial Revolution
- Market forces vs "command-and-control"

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Dancing Molecules and Heat Rays!

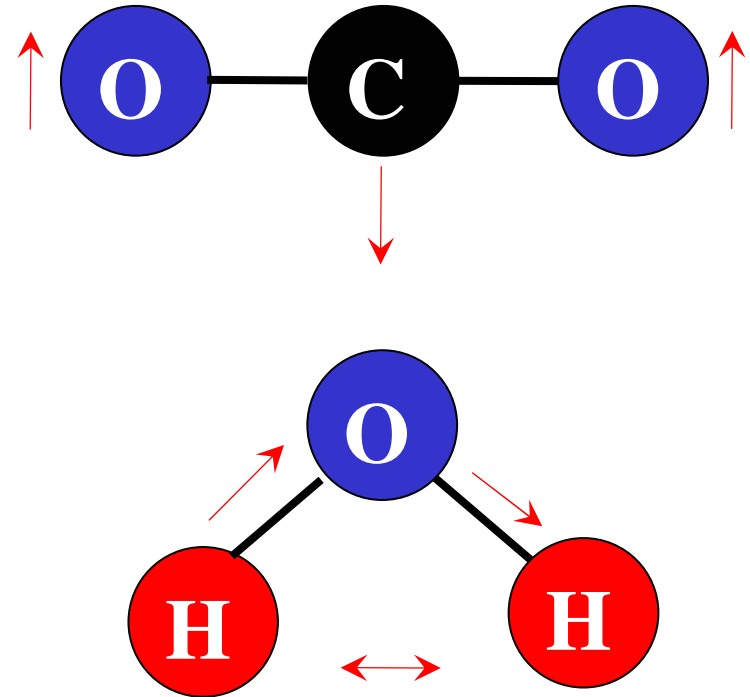
- Nearly all of the air is made of oxygen (O_2) and nitrogen (N_2) in which **two atoms of the same element** share electrons
- Infrared (heat) **energy radiated up from the surface can be absorbed** by these molecules, but not very well



Diatomic molecules can vibrate back and forth like balls on a spring, but the ends are identical

Dancing Molecules and Heat Rays!

- Carbon dioxide (CO_2) and water vapor (H_2O) are different!
- They have **many more ways to vibrate** and rotate, so they are very good at absorbing and emitting infrared (heat) radiation



Molecules that have many ways to wiggle are called “Greenhouse” molecules

Solar radiation powers the climate system.

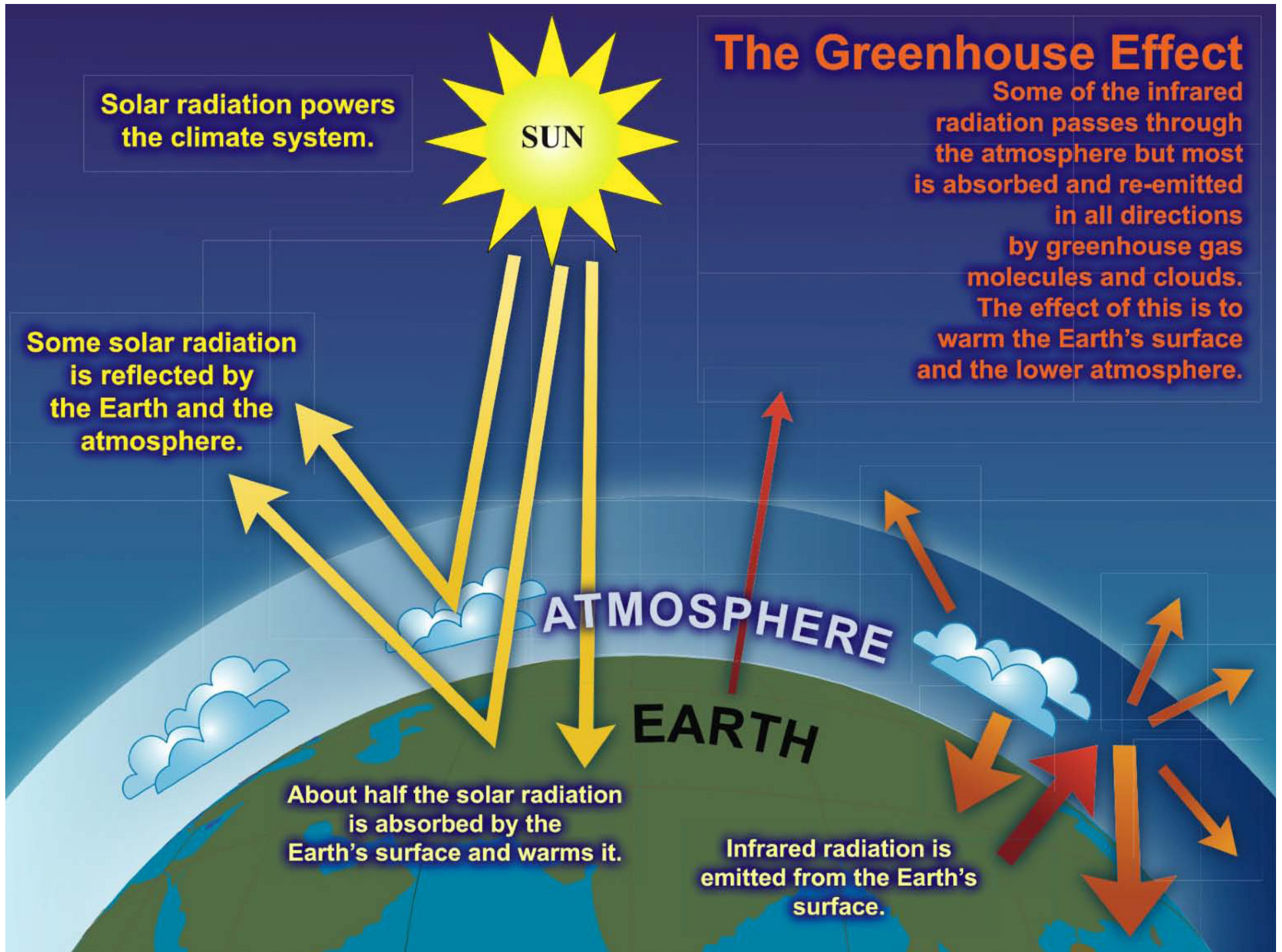
The Greenhouse Effect

Some of the infrared radiation passes through the atmosphere but most is absorbed and re-emitted in all directions by greenhouse gas molecules and clouds. The effect of this is to warm the Earth's surface and the lower atmosphere.

Some solar radiation is reflected by the Earth and the atmosphere.

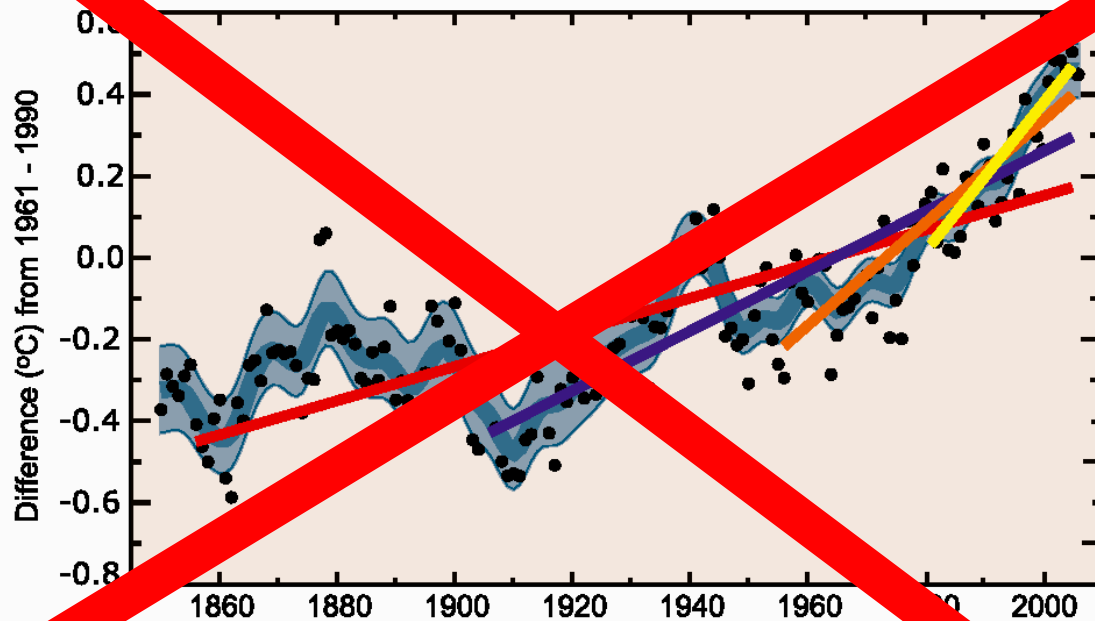
About half the solar radiation is absorbed by the Earth's surface and warms it.

Infrared radiation is emitted from the Earth's surface.



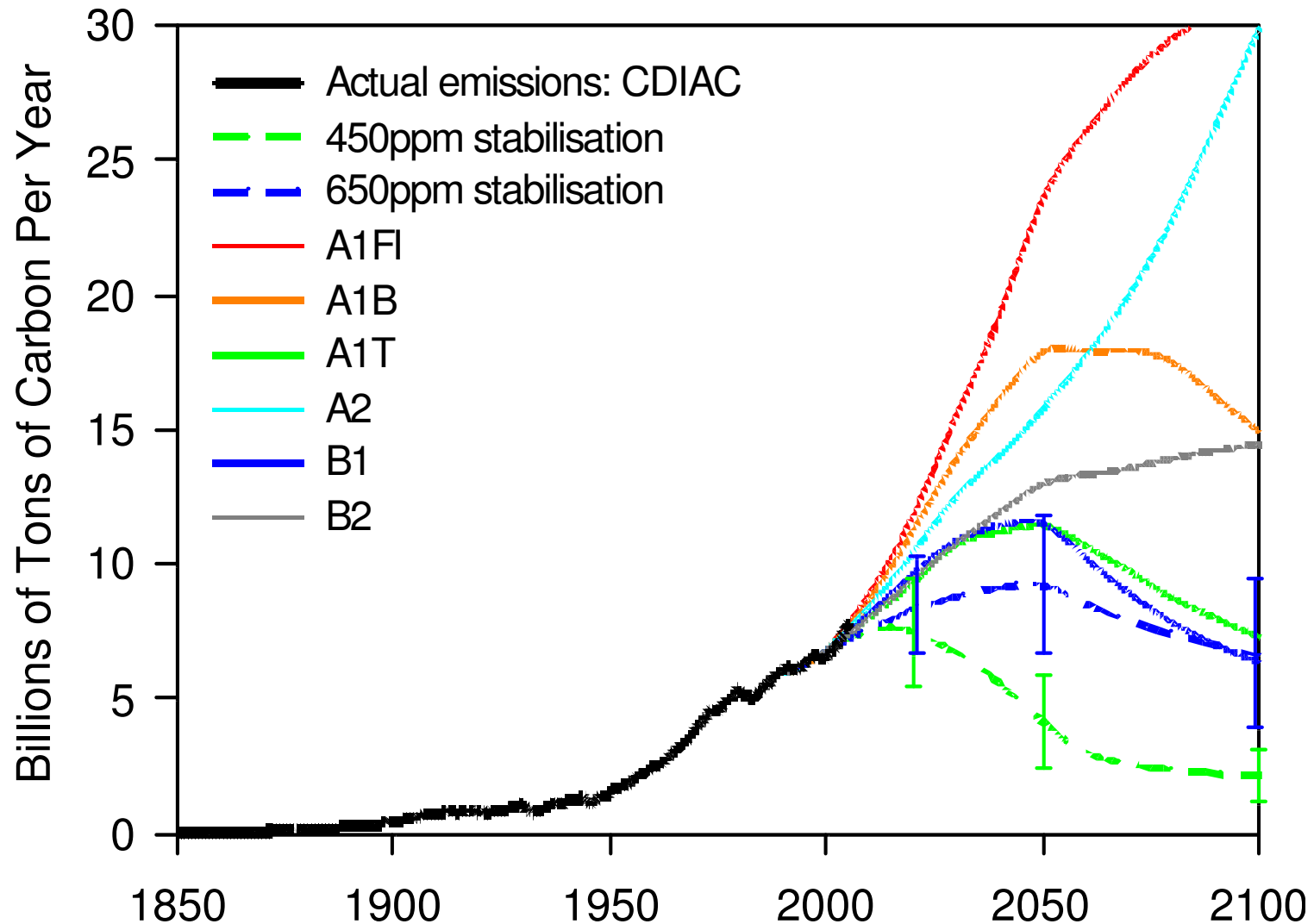
Common Misconception #1

"Expectations of future warming are based on extrapolation of recent warming trends"



WRONG! They are based on the idea that when we add energy to the surface, it will warm up

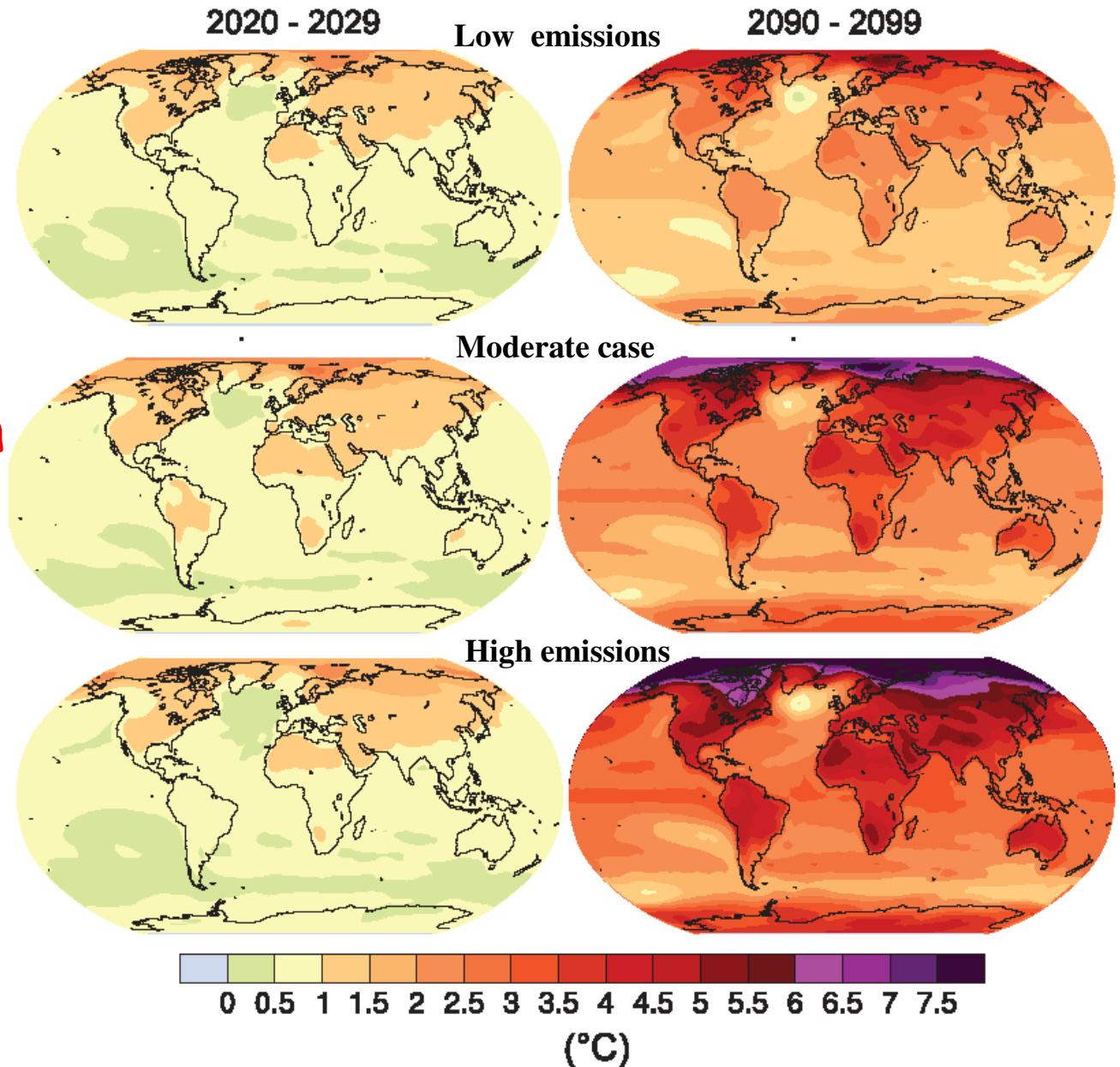
Future Emission "Scenarios"



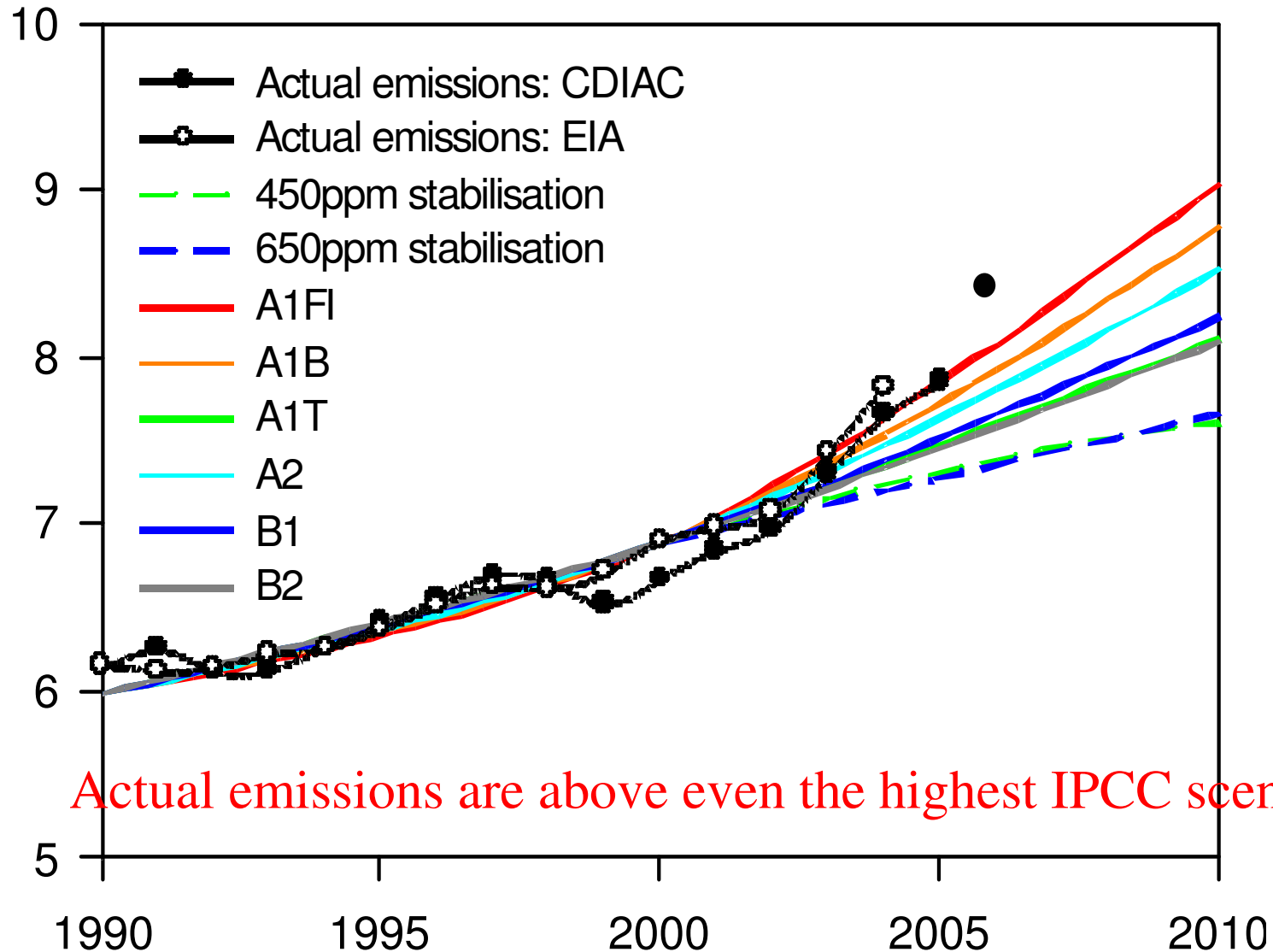
Economists & Demographers: Different *self-consistent* “*stories*” about population, economic growth, technological development, trade, etc ...

Global Projections of Surface Temp

- Land vs ocean!
- North vs South
- Global mean warming of 2° to 5°
- North American warming of 3° to 6° C
= 5° to 11° F
- Arctic warming of 8° to 14° F
- "only" a 1-in-6 chance of 25° F warming here!



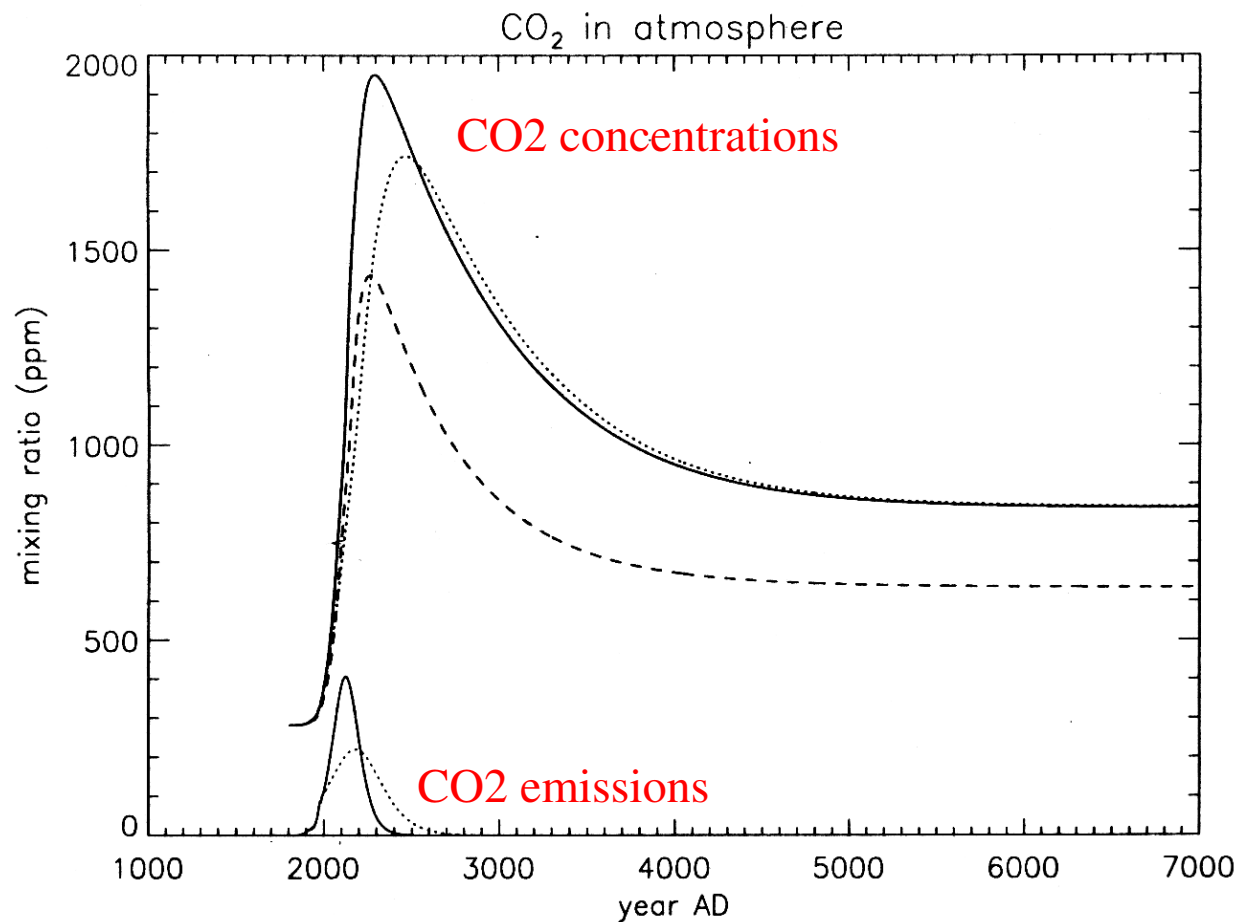
Emission Scenarios vs Reality



Actual emissions are above even the highest IPCC scenarios

Common Misconception #2

"When we reduce or stop the burning of fossil fuel, the CO_2 will go away and things will go back to normal"



CO₂ from fossil fuel will react with oceans, but only as fast as they "mix"

About half of the fossil CO₂ will stay in the atmosphere for many thousands of years after emissions stop!

Historical Perspective

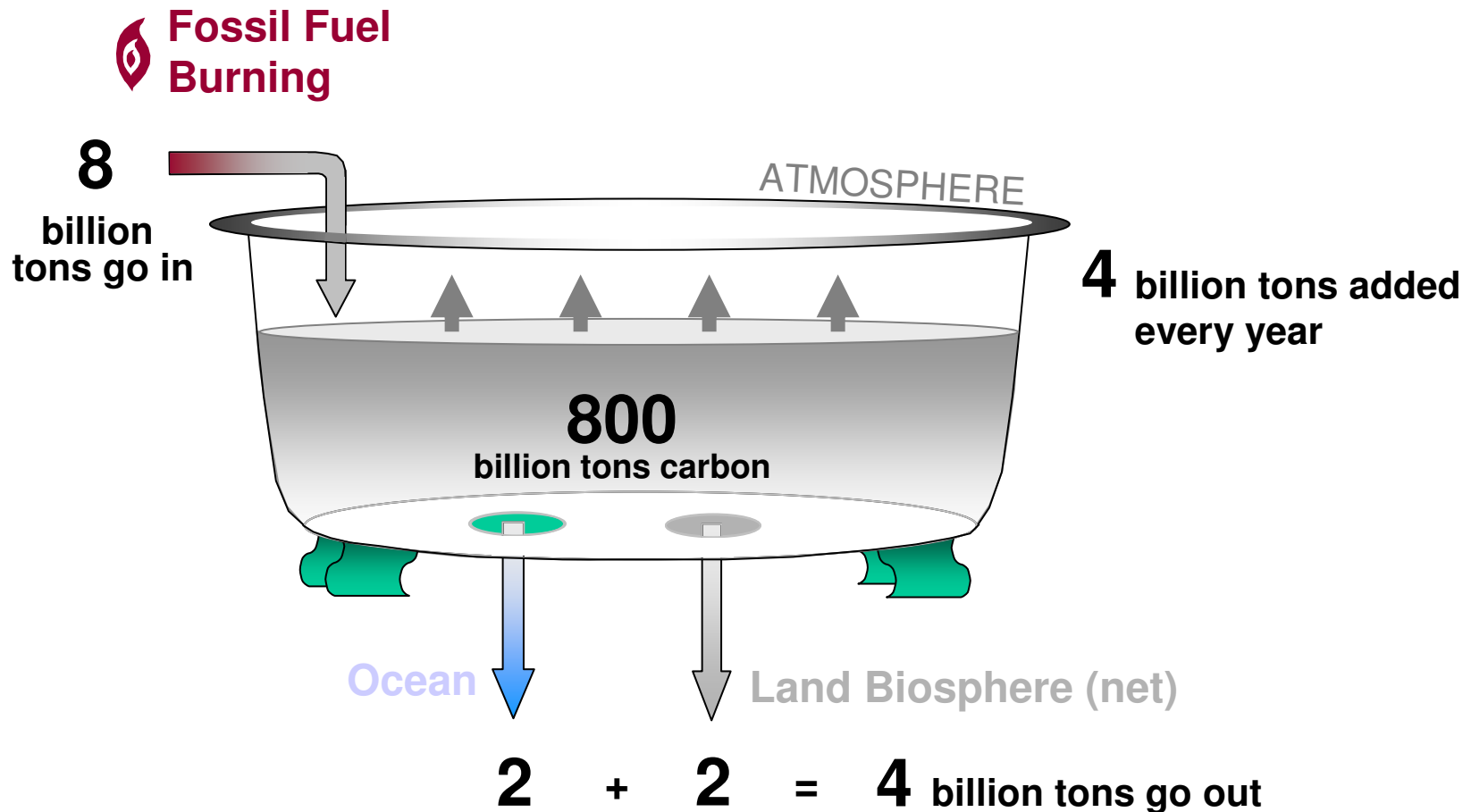


Climate change, CO₂, and energy will likely **be dominant themes in human history for centuries**, much as religious wars, feudalism, colonialism, and industrialization in the previous millenium

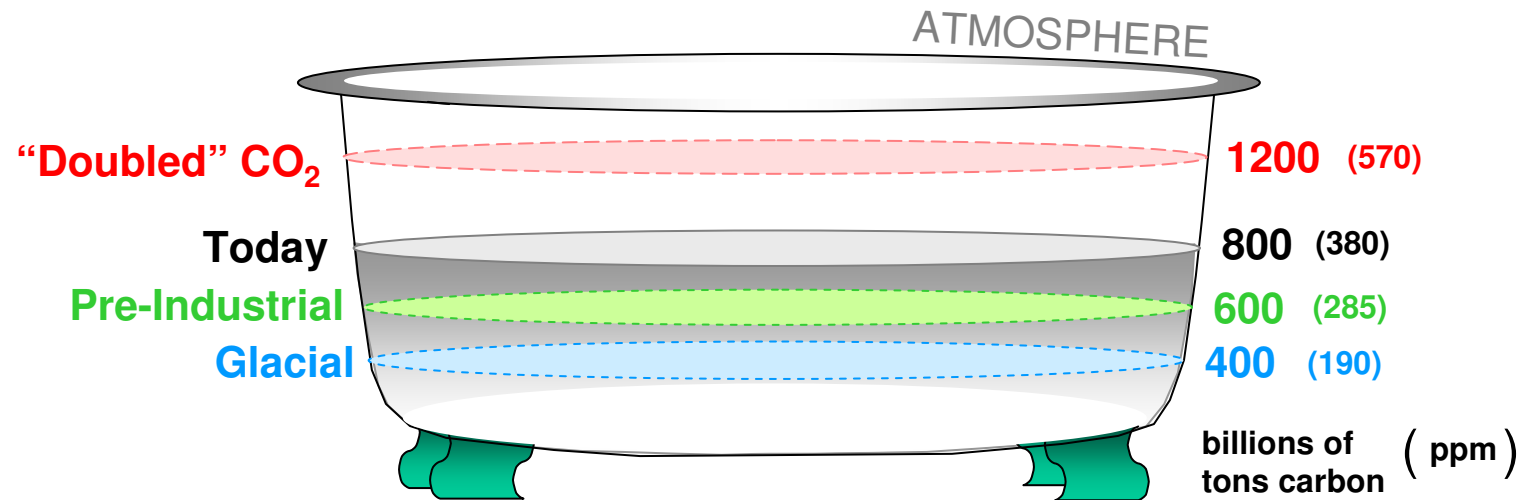
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CO₂ "Budget" of the Atmosphere

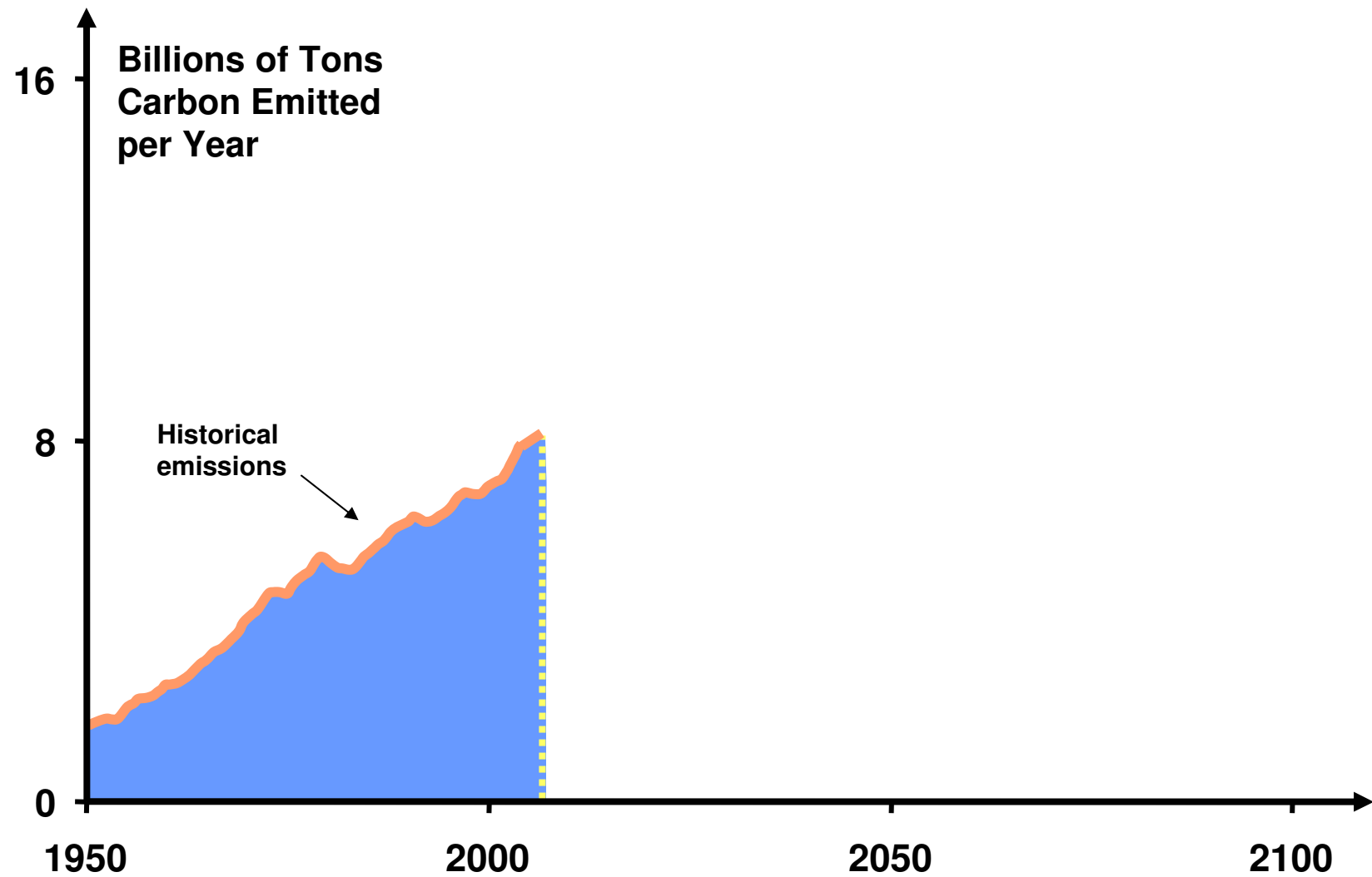


How Far Do We Choose to Go?

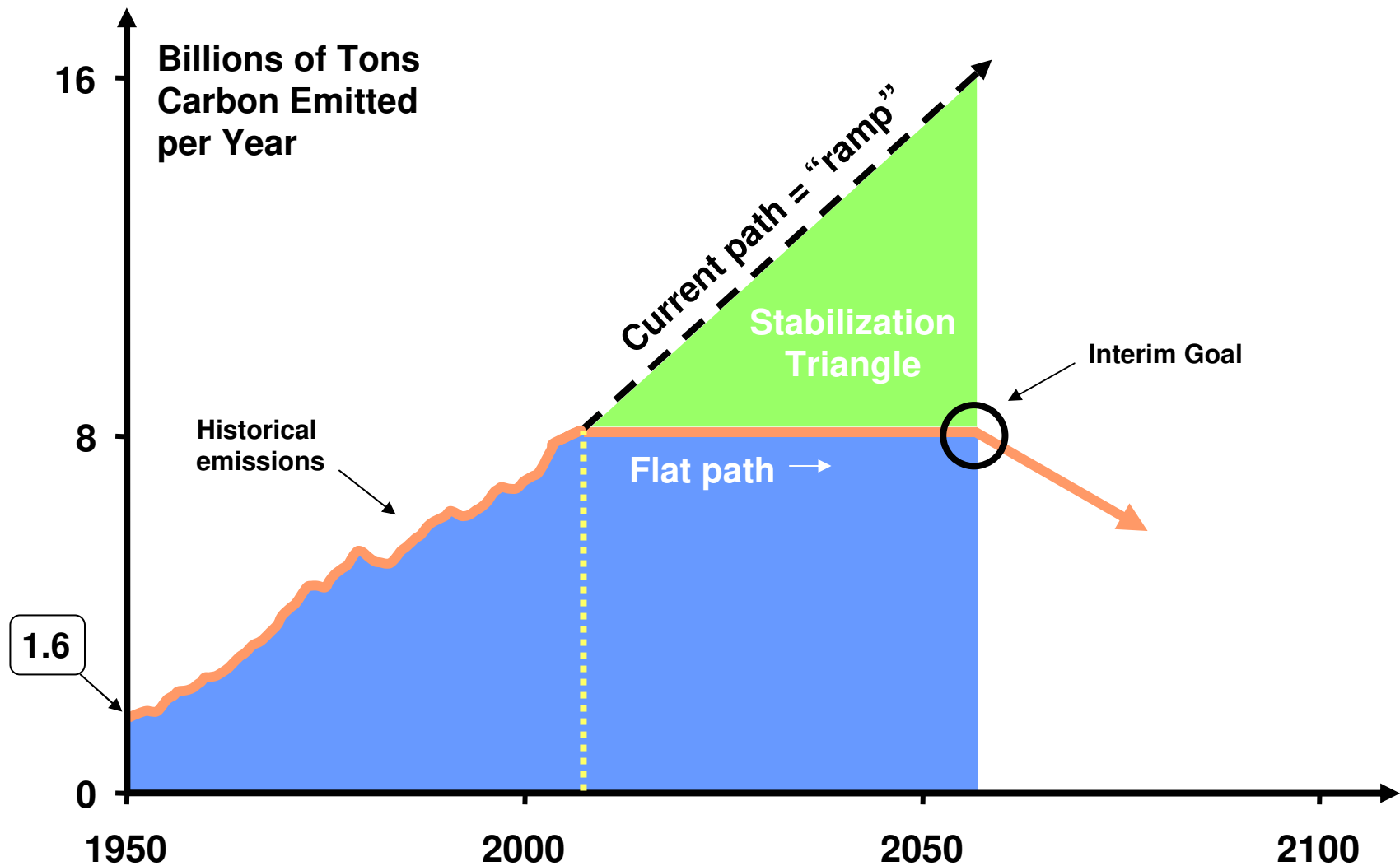


Past, Present, and Potential Future
Carbon Levels in the Atmosphere

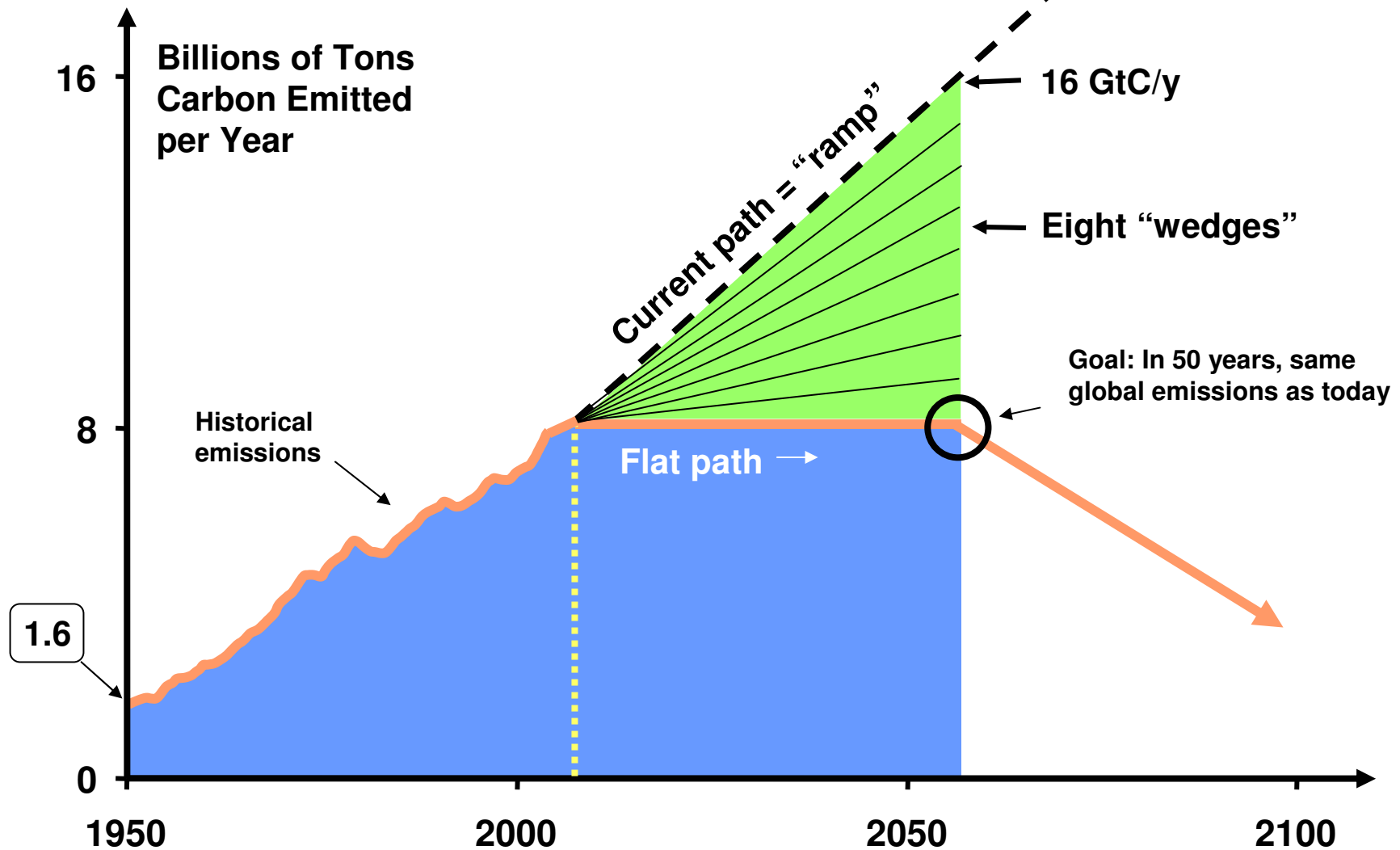
Historical Emissions



The "Stabilization Triangle"

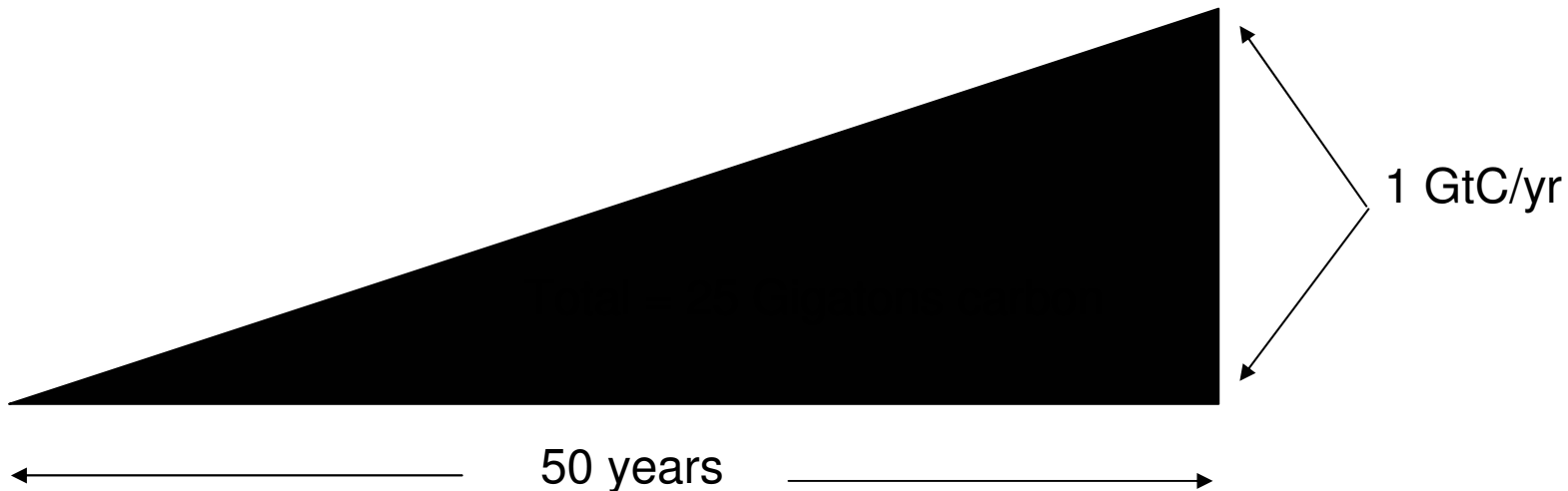


"Stabilization Wedges"



What is a "Wedge"?

A "wedge" is a strategy to reduce carbon emissions that **grows** in 50 years from zero to 1.0 GtC/yr. The strategy has **already been commercialized at scale** somewhere.

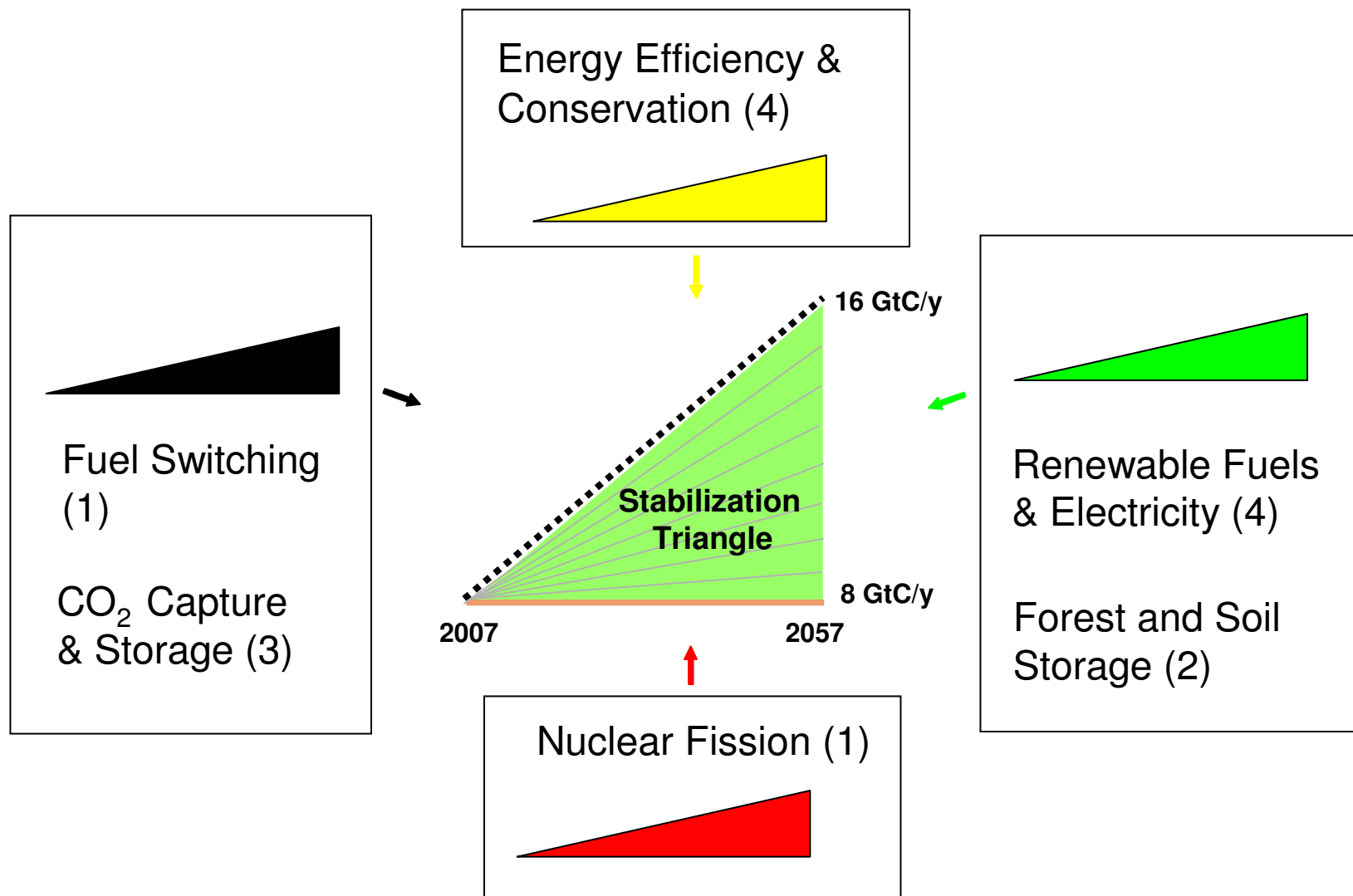


Cumulatively, a wedge redirects the flow of 25 GtC in its first 50 years. This is 2.5 trillion dollars at \$100/tC.

A "solution" to the CO₂ problem should provide at least one wedge.



Fifteen Wedges in 4 Categories



Efficiency



Double the fuel efficiency of the world's cars or halve miles traveled

There are about 600 million cars today, with 2 billion projected for 2055



Produce today's electric capacity with double today's efficiency

Average coal plant efficiency is 32% today



Use best efficiency practices in all residential and commercial buildings

Replacing all the world's incandescent bulbs with CFL's would provide 1/4 of one wedge

E, T, H / \$

Sector s affected:

E = Electricity, T =Transport,
H = Heat

Cost based on scale of \$ to \$\$\$



Fuel Switching



Photo by J.C. Willett (U.S. Geological Survey).

**Substitute 1400 natural gas electric plants
for an equal number of coal-fired facilities**

E, H / \$

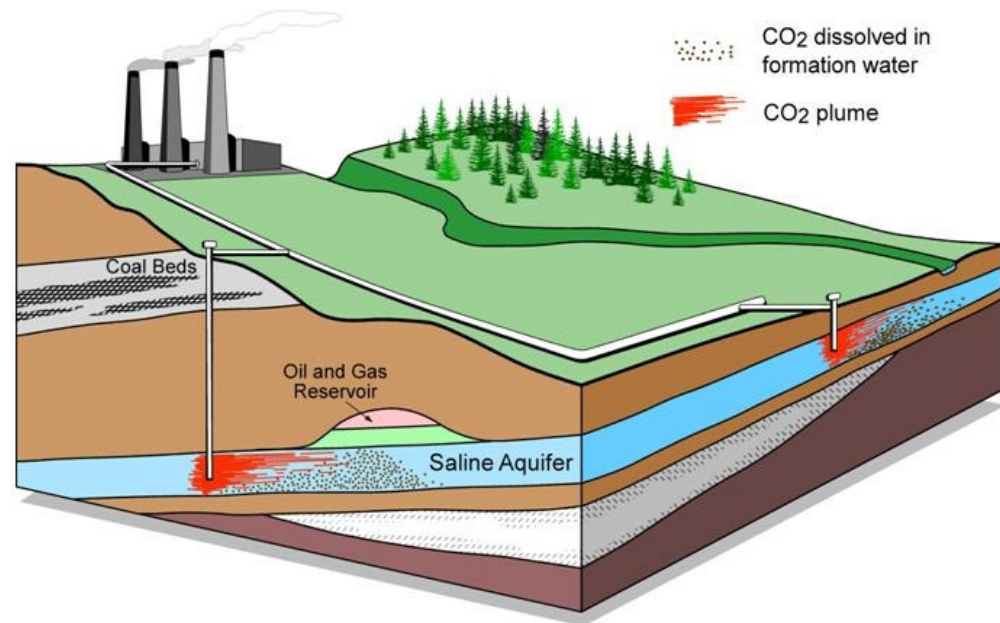
**A wedge requires an amount of natural gas equal
to that used for all purposes today**



Carbon Capture & Storage

Implement CCS at

- 800 GW coal electric plants *or*
- 1600 GW natural gas electric plants *or*
- 180 coal synfuels plants *or*
- 10 times today's capacity of hydrogen plants



Graphic courtesy of Alberta Geological Survey

E, T, H / \$\$

There are currently three storage projects that each inject 1 million tons of CO₂ per year – by 2055 need 3500.



Nuclear Electricity

**Triple the world's nuclear
electricity capacity by 2055**



Graphic courtesy of NRC

The rate of installation required for a wedge from electricity is equal to the global rate of nuclear expansion from 1975-1990.

E/ \$\$



Wind Electricity



Photo courtesy of DOE

**Install 1 million 2 MW
windmills to replace coal-
based electricity,**

OR

**Use 2 million windmills to
produce hydrogen fuel**

E, T, H / \$-\$\$

A wedge worth of wind electricity will require
increasing current capacity by a factor of 30





Solar Electricity

**Install 20,000 square kilometers for
dedicated use by 2054**



Photos courtesy of DOE Photovoltaics Program

A wedge of solar electricity would mean increasing current capacity 700 times

E / \$\$\$





***We choose to do
these things not
because they are
easy, but because
they're hard!***



President John F. Kennedy Ri

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Imagine it's 1800, and you're in charge ...

Somebody presents you with a grand idea for transforming the world economy:

- ✓ Dig 8 billion tons of carbon out of the ground every year
- ✓ Build a system of pipelines, supertankers, railroads, highways, and trucks to deliver it to every street corner on the planet
- ✓ Build millions of cars every year, and millions of miles of roads to drive them on
- ✓ Generate and pipe enough electricity to every house to power lights & stereos & plasma TVs

... *"and here's the itemized bill ..."*

Thinking about Costs

- Our global society built that very system
- We didn't go broke building it ...
- We got rich beyond the avarice of kings!
- Now we have to do it again!
- How?

Putting a Price on Carbon Emissions

- A new industrial revolution won't happen because people want to "do the right thing"
- The government can't just pass a law and create a new global energy economy, any more than they could 200 years ago
- If low-carbon-footprint goods and services cost less than "dirtier" ones, people will buy them
- The role of policy is to provide incentives, to put a price on carbon!

A Policy Spectrum

“command and control”

“market capitalism”

direct
subsidy

“cap and trade”

“tax and rebate”

Conclusions

- Rising levels of CO_2 will cause **significant climate change** in the 21st century and far beyond
- The only way to mitigate these changes is to **stop burning coal, oil, and gas**
- This can **feasibly be done using today's technology**, but requires tremendous will
- Solving the climate problem will lead to a **new industrial revolution**, and huge wealth creation
- Dealing with this problem will be a **major theme of history** for centuries to come